3S^2: Behavioral Response Studies of Cetaceans to Navy Sonar Signals in Norwegian Waters

Patrick Miller
Sea Mammal Research Unit
Scottish Oceans Institute
School of Biology
University of Saint Andrews
St. Andrews Fife, KY16 8LB UK
phone: (+44) 1334-463554 fax: (+44) 1334-463443 email: pm29@st-and.ac.uk

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http://www.smru.st-and.ac.uk

LONG-TERM GOALS

One primary goal of this international cooperative research program is to investigate behavioral reactions and the sound exposures required to elicit them of three species of whales: bottlenose whales, minke whales, and humpback whales to naval active sonar signals in the 1-10 kHz range. The results will be interpreted to generate dose-response functions in order to help establish safety limits for sonar operations for these species. Another primary goal of the program is to experimentally assess the effectiveness of "ramp-up," a common mitigation protocol in which source levels are gradually increased prior to the onset of full-level transmissions. Ramp-up is designed to give nearby animals some time to move away before sonar transmissions reach maximum levels. However, it is unknown whether or not this protocol is actually effective for animals in their natural environment. We have developed and implemented an experimental design to test whether the 'ramp-up' procedure is an effective protocol to reduce risk of harm from sonar activities.

OBJECTIVES

In this research project, our specific objectives are to: 1.) Expand the 3S comparative experimental dataset to include species that are potentially more sensitive even if they are difficult to study: Northern bottlenose whale (*Hyperoodon ampullatus*, family Ziphiidae) and minke whale (*Balaenoptera acutorostrata*, family Balaenopteridae). The goal is to identify behavioral response thresholds during exposure experiments, and to compare these to responses to no-sonar controls and playback of killer whale sounds; 2.) Conduct a directed study on the effectiveness of ramp-up as a mitigation method with abundant and relatively easy-to-study humpback whales (*Megaptera novaeangliae*, family Balaenopteridae); 3.) Record sufficient no-sonar baseline data of all target species to statistically compare experimental records with baseline records and to adequately describe the behavioral significance of recorded changes in behavior; and 4.) Develop collaborations between the 3S research group with other research groups undertaking similar projects to pool data where appropriate, share expertise and reduce overall project costs.

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APPROACH

Two of the species of whale selected for this study are North Atlantic species for which there is evidence of risk from sonar exposure. Sonar-related strandings have commonly involved Ziphiids in temperate or tropical waters, but have also included species that are more common the North Atlantic: the Northern bottlenose whale (Canary Islands), and the minke whale (Bahamas). It is unclear whether the low numbers of Northern bottlenose whales and minke whales documented in sonar-related stranding events result from lower sensitivity to sonar or because they are present in lower numbers in the areas where stranding events have been documented. To resolve this question, directed research on the behavioral responses of these two species is needed (Tyack et al., 2004). The earlier 3S research effort (see related programs) with killer, sperm, and long-finned pilot whales provides a dataset that enables comparative analysis of behavioral response sensitivities. The $3S^2$ field experiments follow the same protocol of escalating the level received by the whale subject in order to identify response thresholds. Playback of killer whale sounds is conducted to assess how responses to sonar might be shaped by reactions to naturally aversive stimuli.

Similar experimental data are needed to address the question of whether or not ramp-up is an effective mitigation measure. Animals swimming close to the location of the first full-level sonar transmission are at the greatest risk of severe effects such as strong behavioral responses or hearing effects such as temporary or permanent threshold shift (left panel of Fig. 1). The ramp-up protocol could be effective if it gives animals time to move away from the immediate location of the full-level sonar pings (right panel of Fig. 1). Thus, the ramp-up protocol is itself is based upon the principle of <u>behavioral response</u> – in this case an avoidance response that protects the animals from receiving intense sound levels.

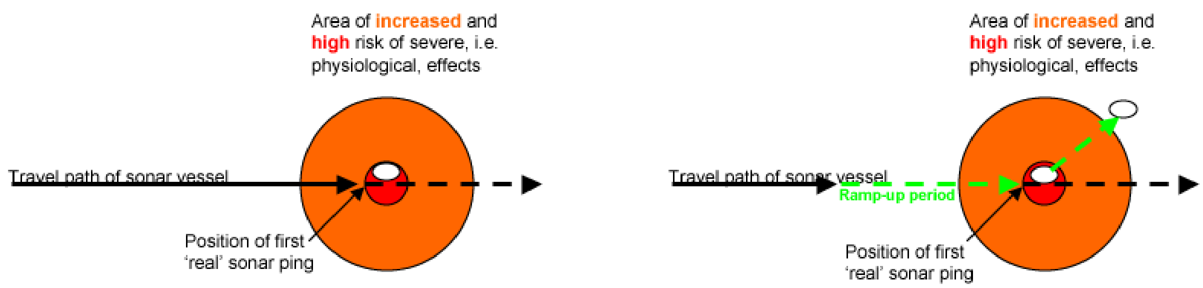

Figure 1. A conceptual diagram of the role of ramp-up before full-level sonar operations. Left: Animals near the position of the first full-power sonar transmissions are at a higher risk of severe effects. Right: The ramp-up procedure implies that sonar sounds are started earlier, at lower levels, and are gradually increased to full power at the planned position. These additional ramp-up transmissions are designed to give animals near the zone of increased risk time to move away.

Specifically, it is assumed that animals will move away from the source of sounds during ramp-up, even if the sounds are transmitted at relatively low source levels. Avoidance has been observed in several studies of marine mammals in the presence of noise (Richardson et al., 1995), but does not necessarily always occur (Miller et al., 2009). It is even possible that starting the sonar sounds at low levels will cause the animals to acclimate to the sound, thereby reducing any tendency to avoid the source. Second, it is assumed that animals will be able to sense the direction and path of the oncoming sound source and formulate a good direction to move away from the sound source. Moreover, it may take some time for animals to determine the direction and speed of movement of the vessel to make appropriate avoidance movements.

To study the effectiveness of ramp-up as a mitigation tool, we are quantifying the likelihood of avoidance as a consequence of exposure to the ramp-up signals. Thus, it becomes critical to understand what factors affect the probability of avoidance (e.g. received level at the animal, distance of the source, frequency or amplitude of the sonar, sound propagation conditions, behavioral state of the animal). As in behavioral response studies generally, we seek to understand what the consequences for the animals are, but in the case of ramp-up we specifically would like to know whether avoidance behavior leads to effective protection from high sound exposure levels or not.

The research is carried out by an international collaborative team from the Sea Mammal Research Unit (SMRU), Woods Hole Oceanographic Institution (WHOI), Norwegian Defense Research Establishment (FFI), and Netherlands Organization for Applied Scientific Research (TNO). WHOI provides v2 Dtags, and tagging support for the field work. Project management and logistic support, including acquisition of research vessels and permitting are managed through FFI, led by Dr. Petter Kvadsheim. FFI also provides biological and tagging expertise, including the development of a new pneumatic launching system for the Dtag, with the FFI part of the effort headed by Lars Kleivane. TNO contributes an advanced towed array system for recording and detecting marine mammal sounds (Delphinus), a multi-purpose towed source (Socrates), and staffing during the cruises under the leadership of Frans-Peter Lam, with collaboration from René Dekeling of the Royal Netherlands Navy. The Socrates source is capable of transmitting 1-2 kHz signals at a source level of 214dB re1μPa m, and 6-7 kHz signals at a source level of 199dB re1μPa m. Miller of SMRU at the University of St Andrews leads the analysis team and Tyack also from SMRU is a member of the $3S^2$ board, provides scientific advice, oversees postdoctoral research, and acts as liaison with the WHOI tagging team.

WORK COMPLETED

In this fiscal year, we conducted two research trials under this program, a baseline trial focusing on the long-finned pilot whale, and a sonar-exposure trial primarily focused upon conducting more controlled sonar exposure experiments to northern bottlenose whale and minke whales. The baseline trial was carried out in May-June 2013 and focused upon conducting playback experiments of mammal-eating killer whale sounds with additional control stumuli also tested. The sonar exposure trial was the third of three planned month-long sonar-experimental trials for the 3S2 project. The sonar exposure trial focused research on waters off Jan Mayen in June-July 2013 with a primary emphasis on tagging and conducting dose-escalation sonar exposure experiments with the least studied of our new target species: bottlenose and minke whales. We also supported two short pilot efforts of our Norwegian collaborators focused upon tagging minke whales using a barb tag as was used in the successful 2011 experiment with the minke whale. In this fiscal year, we also continued analysis and publication of data collected under this research program.

RESULTS

Data collection results:
In the baseline trial, we successfully tagged 4 different pilot whale groups (with a total of 5 Dtags version 2 deployed). Four of the these five Dtag deployments had a Sirtrak GPS logger 'piggy-backed' onto the Dtag. Visual tracking and detailed group-level social observations were also conducted for all of the tag deployments. We were able to conduct a series of playback experiments on three of these four groups, conducting a total of 7 different presentations of killer whale sounds and various control sounds. The data quality of the experiments was very high, with numerous high-quality fixes from the GPS loggers closely matching fixes made visually (Fig 2).

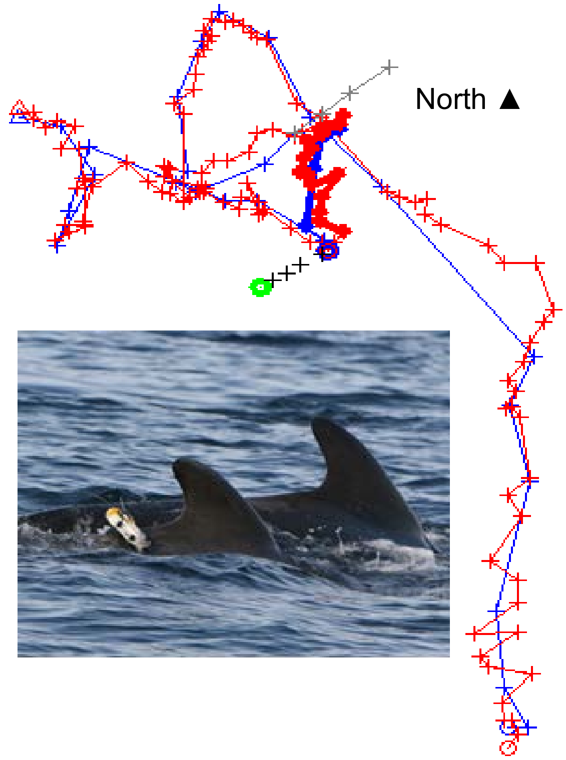

Figure 2. Detailed movement track of tagged whale gm13_169a. The visual sightings are shown in blue, and fixes from the GPS logger are shown in red. Bold sections of the whale track are positions during playback of killer whale sounds. The position of the playback vessel is shown by green and blue circles with x's showing the drifting motion of the playback boat. Note the very high number of fixes from the GPS logger, and the close match between visual and GPS tracks of the whale. Inset box shows the Dtag version 2 with GPS logger (small antenna) attached to a pilot whale.

Initial inspection of the outcomes of the experiments indicate that long-finned pilot whale approached the playback speaker consistently when mammal-feeding killer whale sounds were played (Fig 2). The strong approach behavior is similar to how they were previously found to approach fish-eating killer whale sounds (Curé et al., 2012). Long-finned pilot whales seem to approach diverse sound types, including sounds of possibly threatening mammal-feeding killer whales, but avoided the sonar when it was presented at high source levels (Miller et al., 2012). These initial results seem to indicate a lack of correspondence in how long-finned pilot whales respond to sonar versus how they respond to natural killer whale sounds that might indicate a threat.

The 3S^2 sonar experiment trial was the last of three month-long sonar experiments in this program. In the first two trials we had been very successful at conducting a number of experiments to test the efficacy of the ramp-up procedure with humpback whales (Fig 1). This final trial therefore focused upon the difficult-to-study nothern bottlenose and minke whales, in order to produce a more rounded dataset. In addition to our baseline trial focused upon pilot whales, we supported two additional minke efforts led by FFI, Norway, aimed at refining the system for attaching tags to Minke whales.

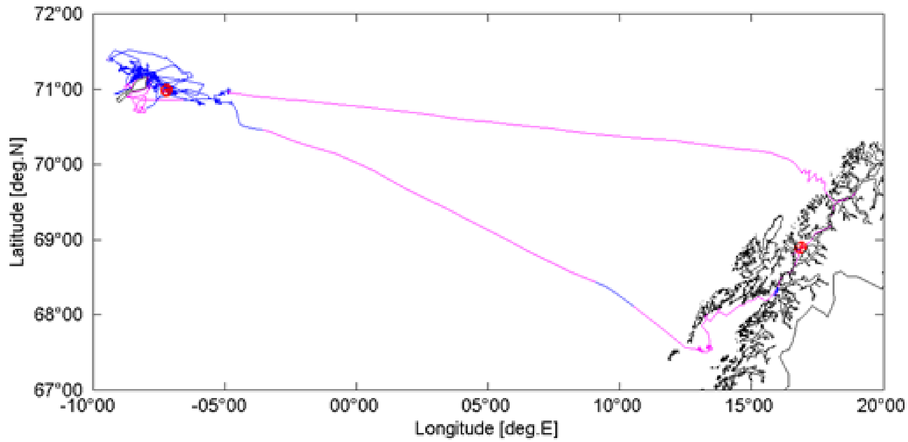

Figure 3. Vessel track of R/V Sverdrup II during the 3S2 sonar trial. Blue indicates periods when TNO's towed hydrophone system was deployed, and red circles indicate locations where the Socrates sonar was used.

Our sonar experiment trial was conducted in Westfjord and off Jan Mayen, in Norwegian waters (Fig 3). We were very successful at finding our target species species in these locations. A total of 91 unique sightings of minke whales were made in Westfjord and the Jan Mayen area and 220 sightings of northern bottlenose whales were made in the waters near Jan Mayen. Despite maximum 24-hr effort by the research team, we were only able to conduct one single sonar experiment during the trial with northern bottlense whales. Minke whales continued to be very difficult to approach closely enough to tag as found in our 2012 trial (Kvadsheim et al., 2012). For bottlenose whales, we initially attempted pole tagging for several days with many close approaches, but no success. On 25 June, we switched tagging systems to the ARTS system developed by our 3S Norwegian collaborators and quickly were able to attach a tag (Fig 4) and subsequently conduct an experiment, detailed below. After that, we were unable to attach another tag due to poor weather, fewer animals, and fewer encounters close enough to attempt tagging.

Analysis of this data-set is ongoing now as a priority for 3S. Data inspection and intial analyses indicate that the deep and long dive following the start of the sonar exposure (Fig 4) was extremely unusal relative to other deep dives in this record as foraging clicks were not produced during the dive. The whale appears to have switched from what started as a shallower dive into the unusual silent deep dive, similar to responses described for Cuvier's beaked whales exposed to sonar (DeRuiter et al., 2013). The sonar experiment conducted with the northern bottlenose whale was an important experiment as it added a new species to the growing collection of experiments with the sensitive species of the beaked whale family Ziphius.

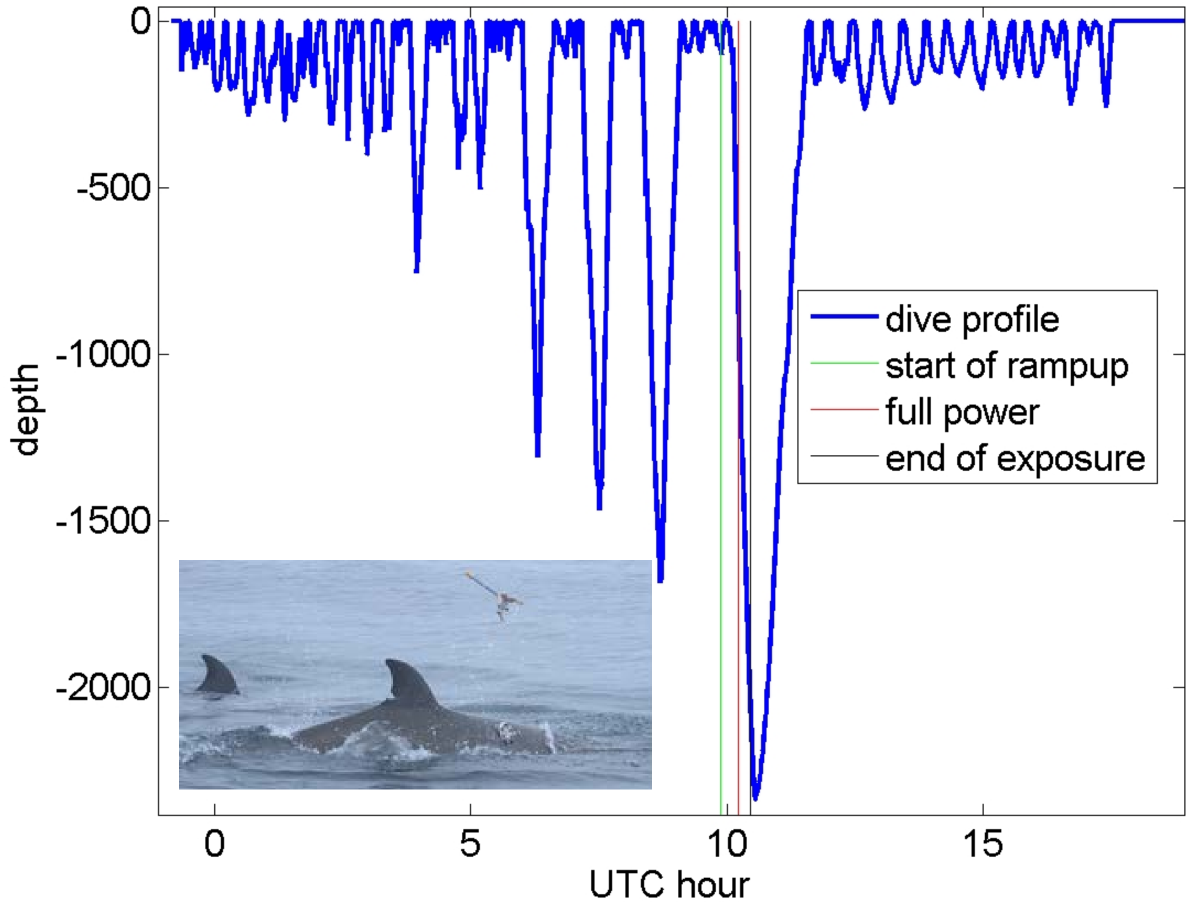

Figure 4. Time-depth profile of bottlenose whale ha13_176a tagged using the ARTS system (inset box), and later exposed to sonar signals noted with vertical lines. Note that the whale conducted an unusually deep and long dive after the start of sonar transmissions.

Data-analysis results:

During the past fiscal year, our team continued analyses of the data collected under this award, as well as further analyses of the baseline behaviour and response to sonar of the 3S species (work done under the first increment of this award). The efficacy of ramp-up has been a focus of important theoretical analyses (von Benda-Beckmann et al., in press) that both used and will strongly support interpretation of the experimental results of our program. Results of our research have been presented at the Effects of Noise on Aquatic Life conference in 2013, and several additional papers have progressed toward publication in peer review journals (see Publication list).

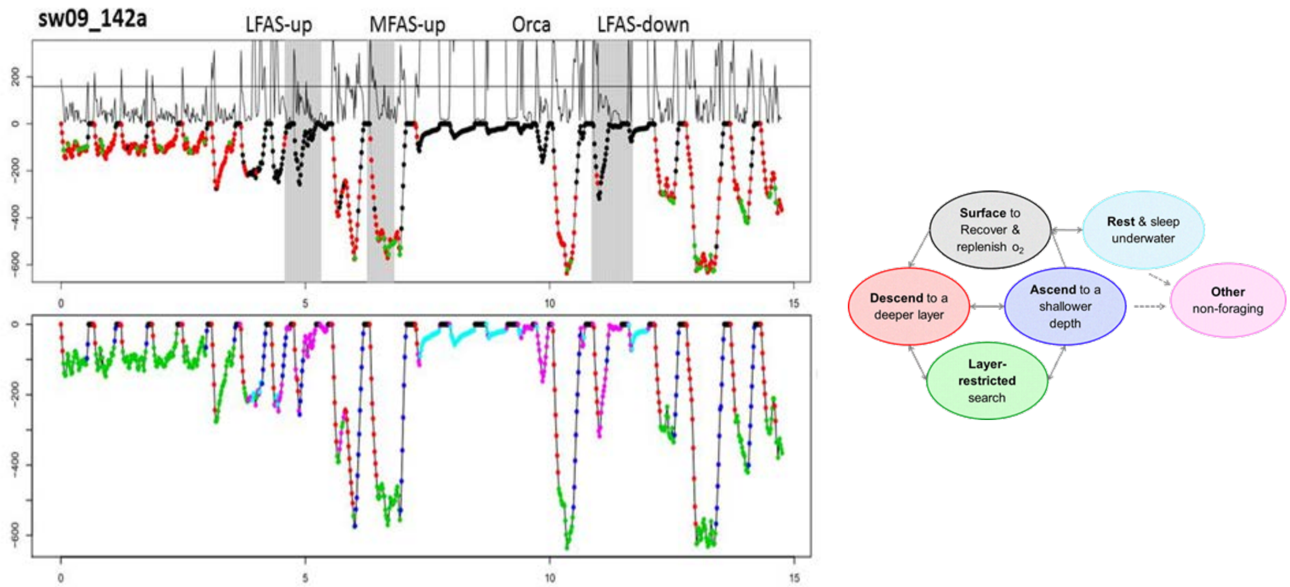

Figure 5. Classification of behavior for sperm whale sw09_142a. The top panel shows the input data used by the classification model. The dive profile is black during silence, red during regular clicking, and green during prey-capture buzzes. The line above the dive profile shows the absolute value of the whale's pitch angle. The bottom panel shows the output of the functional state classification, with colors matching those of the states in far right panel. Sonar exposure sessions and killer whale playback periods are indicated above the time series.

ONR-supported PhD student Saana Isojunno has completed a challenging and important analysis of how sperm whale behavioral budgets are affected by sonar exposure and killer whale playback. The approach uses quantitative analysis of depth changes, pitch, and probability of regular clicking to classify sperm whale behavior into one of 6 different 'functional states' that represent clusters of behavior (Fig. 6). The states were built into a discrete-time hidden state model which described how observed data arise arose from the unobserved, or 'hidden', states in terms of likelihoods. Thus, the states were not a pre-classified model input to the model, but were estimated from the data given state-dependent likelihoods.

The state classifications can then used for further analyses, such as contrast of time budgets across different exposure conditions (Fig. 6). Initial conclusions for the 3S sperm whale data (12 whale records total, 4 with sonar exposure) indicate that sperm whales significantly altered their behavioral time budgets during LFAS sonar exposure and killer whale playbacks in a similar way. Compared to baseline and control periods, they substantially decreased foraging time and increased time spent in the 'other' non-foraging state. Interestingly, behavior changes during LFAS sonar exposure and playback of killer whale sounds were highly similar for sperm whales, unlike apparent dissimilarities noted for long-finned pilot whales. Isojunno's results will form part of her PhD thesis, and are currently being prepared for publication.

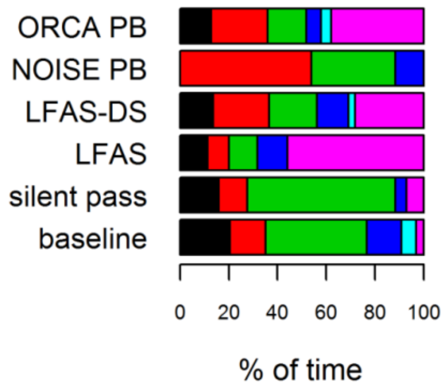

Figure 6. Functional time budgets for 3S sperm whale dataset, broken into different exposure conditions. ORCA PB refers to playback of mammal-eating killer whale sounds. LFAS-DS and LFAS exposure conditions are 1-2 kHz sonar downsweeps and upsweeps, respectively. Note that the percent of time allocated to state 6 increased strongly during LFAS sonar exposures and killer whale playbacks relative to baseline periods.

RELATED PROJECTS

$3S^2$ is the second phase of the project "Cetaceans and naval sonar: behavioral response as a function of sonar frequency" award number N00014-08-1-0984, which expired in 2011. Statistical support and collaboration is ongoing with the MOCHA project award N00014-12-1-0204. This study is conducted in collaboration with WHOI-led award N000140810661 and Kelp Marine award N00014-11-1-0298.

REFERENCES

Curé C, Antunes R, Samarra F, et al. (2012) Pilot whales attracted to killer whale sounds: acoustically-mediated interspecific interactions in cetaceans. PLoS-ONE 7(12): e52201. doi:10.1371/journal.pone.0052201

DeRuiter SL, Southall BL, Calambokidis J, et al. (2013) First direct measurements of behaviour responses by Cuvier's beaked whales to mid-frequency active sonar. Biology Letters 9, doi: 10.1098/rsbl.2013.0223

Kvadsheim, P., Lam, FP., Miller, P., Wensveen, P., Visser, F., Sivle, LD., Kleivane, L., Curé, C., Ensor, P., van Ijsselmuide, S., and Dekeling, R. (2012). Behavioural responses of cetaceans to naval sonar signals in Norwegian waters – the 3S-2012 cruise report. *FFI-rapport* **2012/02058.** (http://rapporter.ffi.no/rapporter/2012/02058.pdf).

Miller PJO, Johnson MP, Madsen PT, Biassoni N, Quero M, Tyack PL. 2009. Using at-sea experiments to study the effects of airguns on the foraging behavior of sperm whales in the Gulf of Mexico. *Deep-Sea Research I* **56**, 1168-1181.

Miller, PJO, Kvadsheim, PH, Lam, FPA, Wensveen, PJ, Antunes, R, Alves, AC, Visser, F, Kleivane, L, Tyack, PL, Sivle, LD (2012). The severity of behavioral changes observed during experimental exposures of killer (Orcinus orca), long-finned pilot (Globicephala melas), and sperm whales (Physeter macrocephalus) to naval sonar. *Aquatic Mammals* **38**: 362-401.

Richardson WJ, Greene CR Jr, Malme CI, Thomson DH. 1995. Marine Mammals and Noise. Academic Press, San Diego, CA.

Tyack PL, Gordon J, Thompson D. 2004. Controlled exposure experiments to determine the effects of noise on marine mammals. *Marine Technology Society Journal* **37**, 41-53.

PUBLICATIONS (Published or submitted peer review articles)

Alves, A, Antunes, R, Lam, FPA, Kvadsheim, PH, Tyack, P, Bird, A, Miller, PJO (in review). Vocal matching of sonar signals by long-finned pilot whales (Globicephala melas). *Marine Mammal sci*

Aoki K, Sakai M, Miller PJO, Visser F, Sato K (2013) Body contact and synchronous dives in pilot whales. *Behavioural Processes* 99, 12-20.

Curé, C., Antunes, R., Alves, AC., Visser, F., Kvadsheim, PH., & Miller, PLO (2013). Responses of male sperm whales (Physeter macrocephalus) to killer whale sounds: implications for anti-predator strategies. *Scientific Reports* **3** : 1579 (DOI: 10.1038/srep01579)

Curé, C, Antunes, R, Samarra, F, Alves, A-C, Visser, F, Kvadsheim, PH, Miller, PJO (2012). Acoustically-mediated interspecific interactions in cetaceans. *PlosOne* **7**:12.

Kuningas S, Kvadsheim PH, Lam FPA, Miller PJO (2013). Killer whale presence in relation to naval sonar activity and prey abundance in northern Norway. *ICES J. Mar. Sci.* (Sept 4. doi:10.1093/icesjms/fst127)

Kvadsheim, PH, Miller, PJO, Tyack, P, Sivle, LD, Lam, FPA, and Fahlman, A (2012). Estimated tissue and blood N_2 levels and risk of in vivo bubble formation in deep-, intermediate and shallow diving toothed whales during exposure to naval sonar. *Frontiers in Aquat. Phyisol.* **3:** article 125.

Miller, PJO, Antunes, R, Wensveen, P, Samarra, FIP, Alves, AC, Kvadsheim, PH, Kleivane, L, Lam, FP, Ainslie, M, Tyack, P, and Thomas, L (in review). Dose-response relationships for the onset of avoidance of sonar by free-ranging killer whales. *J. Acoust. Soc Am.*

Miller, PJO, Kvadsheim, PH, Lam, FPA., Wensveen, PJ, Antunes, R, Alves, AC, Visser, F, Kleivane, L, Tyack, PL, Sivle, LD (2012). The severity of behavioral changes observed during experimental exposures of killer (Orcinus orca), long-finned pilot (Globicephala melas), and sperm whales (Physeter macrocephalus) to naval sonar. *Aquatic Mammals* **38**: 362-401.

Oliviera, C, Wahlberg, M, Johnson, M, Miller, PJO, Madsen, PT (2013) The function of male sperm whale slow clicks in a high latitude habitat: Communication, echolocation or prey debilitation? *J. Acoust. Soc. Am* 133, 3135-3144.

Shamir L, Yerby C, Simpson R, von Benda-Beckmann A, Tyack P, Samarra F, Miller P, Wallin J (submitted) Quantitative analysis of killer and pilot whale sounds using Whale FM. *J. Acoust. Soc Am.*

Shapiro AD, Tyack PL, Seneff, S (2011). Phonemic segment characterization of Norwegian killer whale (Orcinus orca) call types. *Animal Behavior* **81**: 377-386.

Sivle, LD, Kvadsheim, PH, Fahlman, A, Lam, FP, Tyack, P, and Miller, PJO (2012). Changes in dive behavior during sonar exposure in killer whales, pilot whales and sperm whales. *Frontiers in Aquat. Physiol.***3**: article 400

Visser F, Miller PJO, Antunes R, Oudejans M, Mackenzie M, Aoki K, Lam FP, Kvadsheim PH, Huisman J, Tyack P. (in review). The social context of individual foraging behaviour in cetaceans. *Behaviour*

von Benda-Beckmann, A.M., P.J. Wensveen, P.H. Kvadsheim, F.P.A. Lam, P.J.O. Miller, P.L. Tyack, M.A. Ainslie (in press) A theoretical assessment of ramp-up effectiveness at mitigating impact of sonar sounds on marine mammals. *Cons. Biol.*